Appendix IV — Power Indicator Colors and Accessibility[1]

1.1 Introduction

The Power Control User Interface Standard specifies color assignments for power states for indicator lights; the "power indicator" should be green for *on*, amber for *sleep*, and off for *off*. About 8%of the U.S. male and 0.5% of the female population has some form of color deficiency (what is colloquially called "color blindness"). It is important to understand the implications of the user interface standard on this population and consider alternatives. The Professional Advisory Committee specifically asked that we investigate power indicator colors and their impact on accessibility.

Among the reasons to choose the green / amber / off color assignment is consistency with traffic signal light colors, and with the international standard for indicators (IEC 73). While not a power state, when an error is to be indicated red should be used, so we included red in our review of color issues.

Many color-deficient people find green and yellow colors difficult to differentiate[2]. We have anecdotal evidence that some existing office equipment have green and yellow indicator lights not readily distinguishable by many color-deficient people (and specifications of some current bi-color LEDs confirm this). Choosing the right colors can largely eliminate the problem. Even people without color deficiency may benefit by being less likely to misinterpret indicators that are designed to be accessible to the color-deficient. This discussion provides background information to help product designers specify colors for accessibility.

While the term "amber" is often used in the context of power indicators, the traffic signal light literature uses "yellow", so we use that in the remainder of this discussion, except for when product literature uses amber specifically.

1.2 Color Metrics and Perception

Color science is an extremely complex field. It is possible to describe colors in many different ways, some of which depend on how the color is created (e.g. from a light source directly), reflected (as from a printed page), or shown on a computer display. Some descriptions are objective measures of the light itself (e.g. the peak wavelength), but others are keyed to knowledge about how a typical human eye perceives colors.

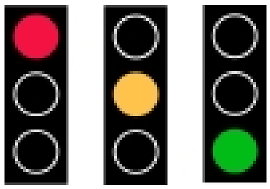
In this discussion, we review three primary measures of color: dominant wavelength (a single frequency — λ_d), CIE *xy* color coordinates (a pair of numbers), and RGB color components for computer monitors (a triad). Printing of colors as with CMYK systems is not addressed. The dominant wavelength is the pure color that will be perceived as closest to the LED color by a typical human eye. LED colors are usually specified by their dominant wavelength, and this is

[1] This appendix provides detailed background information about the development of the Power Control User Interface Standard. For the full report and more about the Standard, see http://eetd.LBL.gov/Controls

[2] The most common form of color deficiency is "deuteranomalia", which is a partial loss of function of green receptors.

usually close to the peak wavelength. Color *xy* coordinates do not address the luminance (intensity) of the light — that would require a third coordinate. Two-dimensional color representations are essentially projections of a three-dimensional space onto two dimensions for convenience and ease of viewing. That such a large area of the CIExy chart (see Figure 1) is green is a combination of the peculiarities of this specific color projection, and how the human eye perceives color.

1.3 Traffic Signal Lights



User confusion with traffic signal lights presents safety issues with potentially deadly consequences. As a result, there has been considerable attention to how traffic lights are perceived by the color-deficient. In recent years, the lamps in many traffic signal lights have been converted to light emitting diodes (LEDs) due to their energy efficiency and lifetime advantages. With traffic lights and power indicators on electronics sharing the same underlying technology and the same key colors, we should look to traffic signals for guidance on how to address color specification for power indicators.

There are two recent studies on traffic lights and color deficiency, one from Europe (CIE, 1994) and one from the U.S. (Freedman, 2001). Both the CIE (International Commission on Illumination) and U.S.-based ITE (Institute of Transportation Engineers) had earlier specified limits for the allowed colors of traffic signal lights; the new studies updated these limits. The recommendations from the two recent studies are not significantly different from the power indicator perspective.

Traffic signal lights are viewed in a significantly different context than office equipment and consumer electronics. They may be viewed from a distance or (relatively) close; there might be bright sun from any direction, or no sun (night); and there can be fog or other impediments to clear viewing. Power indicators, by contrast, are mostly viewed indoors, and mostly under artificial light. Thus, the best limits for power indicator colors may differ modestly from those appropriate for traffic signals, but in the absence of other testing (and none is likely anytime soon), the traffic light recommendations are the best substitute.

1.4 Traffic Light and LED Colors

Figure 1 shows two CIE color charts. On the left chart are placed the color limits specified by the CIE traffic signal light study. Note that the yellow and red regions are at the periphery of the chart (highly saturated). Since LEDs are also highly saturated, we reduced our analysis to the points of these regions along the edge. These points can be described by their *xy* coordinates, their frequency of light (for fully saturated colors), or a RGB combination for rendition on a computer monitor.

The ENERGY STAR specifications for LED traffic lights are based on the 1985 ITE standard. This is fairly close to the CIE standard (as evaluated by (Freedman, 2001)).

Most power indicators are LEDs, so it is worth knowing what LED manufacturers produce and how they characterize the colors. The following is drawn from a sample of current product specification sheets. As expected, LED traffic signal light products use colors within the CIE ranges, but LEDs for non-traffic signal applications use much wider ranges, particularly for green.

In (HP, 1977) it is noted that "a *yellow* LED [585 *nm*] is *yellowish-orange* and a *green* LED [572 *nm*] is actually *greenish-yellow*". This was written in 1977 when color choices for LEDs were more limited, but many LEDs sold today match this pattern.

Green

The limit in the CIE recommendations is 498 to 508 *nm*. Green LEDs sold by Agilent range widely, at least from 505 to 572 *nm* — the latter in a bi-color LED with yellow only as far away as 586. LEDs for traffic signal lights are usually 505 *nm* (e.g. Dialight). Luxeon / Lumileds calls a 505 *nm* LED "cyan", and sells a 530 *nm* LED called "green".

Manufacturers should clearly pay attention to specifying greens in the CIE color range (at the blue end of the green range).

Yellow

The CIE specification for yellow traffic lights is from 585 to 593 *nm*. The 1931 CIE color chart defines *yellow* as about 575 to 580 *nm*; the traffic light colors span the middle of *yellowish-orange* to the early part of the *orange* space; thus, a yellow traffic light is more orange than yellow. Agilent sells yellow at 586 *nm*; Dialight at 590 *nm*. Luxeon / Lumileds calls a 590 *nm* LED "Amber".

Regarding traffic signals, the "pedestrian orange" color (CIE) is 595 to 610 *nm*. For yellow, there are variants on the upper end of the yellow range, for particularly high or low illuminance. In the absence of better information, we used the normal illuminance value.

Red

Red in the traffic signal specification ranges from 615 to 705 *nm*.

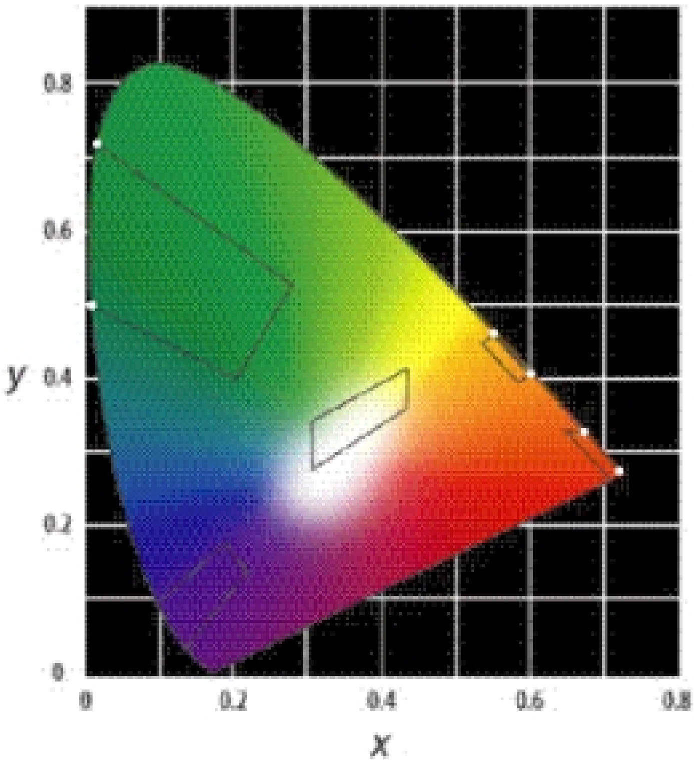
1.5 RGB Colors

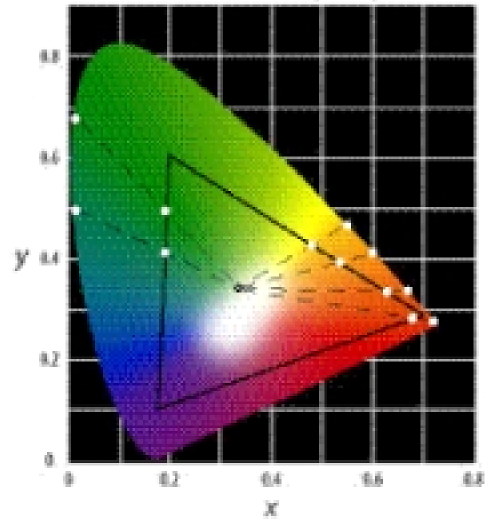
Red-Green-Blue (RGB) colors will be used on power indicators shown on computer displays. An example is a list of printer icons, that might include the power indicator color to communicate each printer's power state. Power control panels for setting delay times and shutdown dialog boxes may also benefit from use the power state color assignments.

Computer monitors can only show a portion of the full color space, so RGB values for them are for the closest approximation that a particular display can show. The RGB values presented here are for a typical CRT. Figure 1 shows how pure colors are projected on to a CRT gamut (the triangle on the right side).

That the green colors appear slightly bluish is to be expected; this helps maintain maximum differentiability from the yellow for those who have trouble distinguishing them. This color chart is adapted from one available on the Adobe, Inc. web site. As shown here it may not be quantitatively precise, but is sufficiently good for illustrative purposes.

Figure 1. CIEXYZ color chart annotated with CIE traffic signal light limits.





	G min	G max	Y min	Y max	R min	R max
x	0.012	0.009	0.545	0.592	0.680	0.735
y	0.494	0.720	0.454	0.407	0.320	0.265
nm	498	508	585	593	615	705

1.6 Web colors

Another set of colors are the 216 standard "web colors" often used on web browsers. These are derived by combining each of six different intensities each of red, green, and blue in every possible combination. In HTML, colors can be expressed as `RRGGBB` hexadecimal numbers (each digit in the range 0..9 or A..F) to represent a range of 0 to 255 for each color (in some cases we list two web colors when the range limit falls between two color). The green range spans from `00FF99` to `00FF33` (a 3-color range); yellow from `FF9900`/`FFCC00` to `FF6600`/`FF9900` (only one color clearly within the range); and red from `FF3300` to `FF0000` (two colors).

1.7 Recommendations

In summary, we found no technical obstacles to making power indicators more accessible to the color-deficient, and found sound technical basis for specific color limits to utilize. We recommend that designers of future electronic products (and by extension to those who manufacture and market LEDs used for power indicators) use the color limits specified in Figure 1. For LEDs, these are 498 to 508 *nm* for green, 585 to 593 *nm* for yellow, and 615 to 705 *nm* for red.

1.8 References

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